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Effects of Climate Variability and Climate Change on Sorghum Productivity in the Cercle of Koutiala in Mali

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Author's contribution

The sole author designed, analysed, interpreted and prepared the manuscript.

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ABSTRACT

The main objective of this study is to analyze the impact of climatic variables (temperature and precipitation) on sorghum productivity in the Cercle of Koutiala in Mali. To do this, the model of the production function was used to estimate the variation of sorghum yield during a period of 30 years (1986-2015). After the test of the unit root of Dickey-Fuller Augmented (ADF), the estimation of the semi-logarithmic model by the Ordinary Least Square method (OLS) showed that the yield of sorghum was affected by the climatic variables. The increase in average rainfall over the period June-September positively affects the performance to a certain threshold. On the other hand, the average temperatures during June-July have no significant effects on the yield. The temperatures observed during August and September, negatively affect the performance of sorghum during the study period to a certain threshold. The precipitations of August and September have a positive impact but not significant on the yield. The interaction between mean precipitation and average temperature during the same period negatively influences the yield of the sorghum. Indeed, the increase of the precipitation combined with an increase of the temperature for the period June to September causes a reduction in the yield of sorghum. Depending on this situation, it is important and necessary to take measures to mitigate the negative impacts of climate on sorghum yield in the Cercle of Koutiala.

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1. INTRODUCTION

Nowadays, climate change is no longer a hypothesis but a reality. Over the past 30 years, climate change (CC) has been observed at the global level. On a global scale, statistics show that in a century, the earth has warmed by 0.76°C [1]. Changes in many weather phenomena and extreme climates have been observed since 1950. Some of these changes have been associated with human influences on the environment. These phenomena are manifested through various observations such as high variability in rainfall, an increase in average temperatures, a resurgence of extreme climatic conditions such as floods, cyclones, and droughts, etc. In West Africa, the average temperature has increased by 0.78°C over the past 50 years, which is greater than the global average [2]. In Mali, the annual average of the temperature has increased by 0.7 degrees Celsius since 1960, with a rate of 0.15 degrees Celsius per decade [3]. Since the 1970s, the western Sahel has suffered from a rainfall deficit due to strong chronic climate disturbances. These phenomena have also been observed in Mali by a decrease of the rainfall by about 19% from 1961 to 2009 [3]. Mali's climate scenarios for 2025 predict a decrease in rainfall, with loss rates from normal of 2 to 6% and an increase in temperatures of 1°C above the norm. Regarding all these issues, Mali is a slight polluter because it represents 0.06% of GHG emissions worldwide [4]. Climate change affects the agricultural sector in all countries around the world, but this effect is considerable in sub-Saharan Africa because it is mainly subsistence agriculture. In this area, in general, and especially in Mali, agriculture is of the rainy type, very extensive, and little mechanized. It should also be added that producers of cash crops are more supported than those of food products by extension services. As a result, food producers are more vulnerable than cash crop producers. Climate change has a direct impact on agricultural production, such as agricultural systems depend on the nature of the climate [5]. This impact is particularly significant in developing countries where agriculture is the main source of employment and income for the majority of the population. This directly affects agro-pastoral production and yield. Based on the data of the National Agency of Meteorology, it is important to note that in terms of rainfall in Mali during the period 1951-1970, the isohyets varied between 95 mm in Tessalit in the North and 1360 mm at Sikasso in the South. While from 1971 to 2000, isohyets ranged from 70 mm in Tessalit and 1181 mm in Sikasso, a drop of 24 mm in the North and 179 mm in the South in half a century. This often leads to recurrent rainfall deficits, resulting in droughts. Mali experienced five major episodes of drought from 1970 to the present day (2020) and has since been characterized by severe climatic conditions. The temperature projection predicts an increase of 1.2 to 3.6 °C in 2060 and 1.8 to 5.9 °C in 2090 for the whole of the country and a slight decrease in precipitation compared to the last 50 years. Mali's economy is based mainly on the exploitation of natural resources. Unsustainable patterns of exploitation of these resources and increased population pressure have led to their widespread degradation. For example, the annual loss of forest area is estimated at around 100,000 hectares according to the Ministry of the Environment and Agriculture (2011). The degradation of natural resources, in this case, agricultural land, and pastoral resources, has led to a decline in crop production. This production consists of cereal production (millet, sorghum, rice, corn, etc.) mainly intended for self-consumption and the production of cash crops (peanuts, cotton, etc.) intended for selling. Millet and sorghum are the staple crops in Mali. They occupy 80% of cultivated areas and contribute to 49% of food consumption in Mali [6]. The main production regions in 2016 were Mopti, Segou, Sikasso, Koulikoro, and Kayes occupying between 82 and 92% of sorghum and millet production according to the Ministry of Agriculture and Rural Development. Production and yield of millet and sorghum have increased significantly more modestly than those of rice and maize; between 1990/91 and 2008/09, production increased by 68% for millet and 42% for sorghum, compared to 224% for maize and 228% for rice [7]. The annual rate of increase in yields was 1.2% for millet and only 0.8% for sorghum, while cultivated areas increased by an average of 2.1% for millet and 1.3% for sorghum. According to CILSS [6], sorghum is a strategic crop of the future to meet Africa's food needs, due to its ability to withstand drought, even in areas with less than 60 rainy days per year, sorghum can provide a solution to food crises in regions where other cereals, such as rice and maize, cannot survive.

Thus, to meet the food consumption needs in Mali, there are many paths to explore not only to improve cereal productivity but also to adapt it to climatic variations. In the Cercle of Koutiala, the temperature varied from 29.1 °C in 1975 to 29.9 °C in 2006 with a very strong rainfall variation from 664 mm, 1125 mm, and 765 mm for respectively 1975, 1985 and 2006 according to the Regional Meteorological Agency in 2009. The effects of climate change are being felt on agricultural productivity and thus on food security and food prices in Koutiala in such a way that agriculture is becoming more and more a daily struggle [8]. According to a report by the NGO Inter-cooperation Sahel in 2008 [9], farmers do not even know when the winter season begins. This led to a decrease in cereal production in the area. In 30 years, cereal production has dropped by 18%. The decrease in sorghum production was estimated at 6% in 2011 [10]. In general, the impacts of climate change in the Cercle result in highly variable precipitation, extreme events such as long periods of drought, the strong wind from the Sahara often loaded with dust, and winter becomes shorter [8].

The choice of Koutiala was based due to the strong pressure on the land and the negative impacts of climate change, the area is characterized by a semi-arid climate. It is considered the main producing area of cereals (sorghum) in Mali. The area represents 12% of domestic sorghum production in 2011 [10]. Agricultural production activity is highly affected by the climate, mainly via the effect of climatic water balance and temperature on crop yields. The question of measuring the economic impact of this effect arises [11]. The effects of climate change on production are evident, so accurate and robust studies are needed to propose solutions that can positively influence the level of cereal production. The reduction of these effects must be the priority of any country.

From these facts, the central question of this research is whether rainfall and temperatures could have effects on sorghum productivity in the Cercle of Koutiala in Mali. In fact, what is the effect of climate change on sorghum productivity?

- What is the effect of precipitation (rainfall) on sorghum yield?
- What is the effect of temperatures on sorghum yield?

The main objective of this study is to analyze the impact of climatic variables (temperature and precipitation) on sorghum productivity in the Cercle of Koutiala in Mali. Specifically, the study firstly aimed at establishing a relationship between sorghum yield and climatic variables (temperature and precipitation), and to determine the effects of temperature and precipitation on sorghum yield. Malian agriculture is characterized by inadequate and uncertain rainfall, infertile and fragile soils, and a strong increase in temperature year to year. Therefore, we assumed that:

- An increase in rainfall positively influences sorghum yield;
- Increased in temperatures decrease sorghum yield.

The impact of climate change on the agricultural sector and adaptation strategies have been the subject of numerous studies in Mali. Researchers identified the major challenges of adaptation, the role of public action in adaptation, and the methods to be used to build an adaptation strategy. For example, a study of the prospects for climate change was conducted in Mali by [12]. They [13] focused on “Climate change, climate variability and adaptation options in smallholder cropping systems of the Sudano-Sahel region in West Africa”. In their study, [14] analyzed the “Effects of climate variability and climate change on crop production in southern Mali”. They also studied the “Adaptation of sorghum in Mali to climate variability” [15]. But as far as the “Climate Variability and Climate Change on Sorghum Productivity in the Cercle of Koutiala” is concerned, there are no studies to our best knowledge. This study, sought at analyzing the “Effects of Climate Variability and Climate Change on Sorghum Productivity in the Cercle of Koutiala in Mali”, aims to fill this gap.

2. LITERATURE REVIEW

In the early 1980s, it has been a surge in studies on the impacts of climate change on agriculture. Since then, various paths have been explored to model accurately as possible the impact of climate change on this sector [16]. Thus, some authors have preferred to focus on the problem globally [17]. Generally, these studies have shown that, although agriculture would be affected by climate change, this would not jeopardize world food [18].

Many studies figured out that in Africa, especially in tropical Africa, the performance of production systems is highly reliant on the climate [19].

Indeed, the poverty of the populations does not allow them to have access to technological adaptations (mechanization, fertilizers, seeds, irrigation, etc.) and adequate and efficient cultural innovations. This situation is an aggravating factor for the socio-economic impact of climate change, for instance, the droughts of the 1970s caused dramatic famine and the floods of the 1990s caused invaluable losses in crop yields [20]. Important scientific works [21,22] have drawn the attention of the scientific community to the challenges of climate variability and change in Africa. It emerges from analyses and conclusions that climatic disturbances have greatly contributed to impact agriculture in already fragile economies.

According to [23], the yields of food crops (millet, sorghum, maize, etc.) have decreased by more than 60% in the Sahel, due to variations in rainfall alone. Some very deficit years, such as in 1972, the Sahel experienced catastrophic food situations. Export crops, which were profitable before 1970, are no longer profitable because they are unsuitable for the new climatic situation. This is the case for oil palm and tomatoes in southern Benin or groundnuts in Niger [24].

In their studies across Africa, [25], compared the effect of climate variables on agricultural production in countries of Sub-Saharan Africa (SSA) and those of Non-Sub-Saharan Africa (NSSA). They concluded that the climate (temperature and precipitation) has been a major determinant of agricultural production in SSA while the NSSA countries are not affected by the climate in the same way. Precipitation like temperatures in (NSSA) has little effect on production than the other explanatory variables. They are not significant determinants of agricultural production in NSSA whereas they are very important for agriculture in SSA, hence a drop in agricultural production.

Specifically, studies carried out in West Africa have highlighted the effect of climatic variables and their multisectoral impacts, notably on agriculture and food production. In this context, [24] highlighted the impact of climate change on food production through indicators and scenarios in southern and central Benin. Also, in Benin, [26] analyzed the impact of climatic variables on cotton, maize, sorghum, and peanuts production in the commune of Banikoara, using an estimation by the double least square's method, they found that the deficits and the rainfall break both exert positive effects on the production of cotton and maize, contrary to the temperature, which exerts a negative effect, generating a sharp decrease in cotton and maize production. On the other hand, the estimation of the production of sorghum revealed signs contrary to those observed on cotton and maize.

Other studies by [27] and [28] in Senegal and Niger have shown that agricultural yields have experienced drastic deficits due to the adverse effects of current climate change and the estimated yields for 2050 will experience significant declines. In Tunisia, [29] assessed the vulnerability of agriculture in the Jeffara plain (south-eastern Tunisia) to climate change using the Ricardian method. This method consists of expressing the net agricultural incomes according to climatic, edaphic, and socio-economic variables. The objective of the study was, firstly, to assess the sensitivity of agriculture in arid zones to climate change by the Ricardian approach and secondly, to verify the effectiveness of certain adaptation measures that have been initiated to reduce the harmful effects of these climate changes. [30] used the Ricardian approach to assess the impact of climate change on Indian agriculture. The same method has been by in numerous researches, [31,32] respectively in their studies used it to assess the impact of climate change on agriculture in South Africa and Burkina Faso.

In Burkina Faso, [32] analyzed the impact of climatic variables on agricultural income on a sample of 1,530 farmers, using a Ricardian model. The study showed that the relationship between income and climate is non-linear and on the other hand that the marginal impact of temperature on agricultural income is $ 19.9 US per hectare while that precipitation is $ 2.7 US per hectare. Analysis of the elasticities reveals that agriculture is very sensitive to precipitation in Burkina. He estimated that an increase in precipitation of 1% leads to an increase in agricultural income of 14.7%. However, an increase in temperatures of 1% leads to a decrease in agricultural income by 3.6%. Sensitivity analysis has also shown that farmers will lose 93% of their income following a 5°C increase in temperature. Besides, the study showed that the practice of irrigation and access to the extension has a positive effect on agricultural income in Burkina.

Using the Ricardian model, [2] has shown that the change in climatic conditions has significant effects on agricultural production, calorific consumption, and the duration of the lean period in Senegal. Also, the results obtained indicate that climate change will have abrupt effects that will increase the vulnerability of populations, largely rural.

The production function approach was used by [17] to measure the direct effects of a climate change on the agricultural production of different crops and their input requirements (light, herbicides, pesticides, fertilizers, etc.). This approach has also been used by [33], to estimate the impact of climate on crop production. Their studies have shown that climate somehow influences the variation in agricultural production. In Tunisia, in a study, [34] analyzed through the production function approach, the Impact of climate change on the productivity of cereal crops in the region of Beja Tunisia. In this study, it is obvious that climatic factors influence not only the yield per hectare of cereal crops but also the net agricultural income.

For authors like [34], climatic variables (temperature and precipitation) greatly influence agricultural yields in Tunisia. Using a multiple regression model for three cereal crops (durum wheat, bread wheat, and barley), they found that the yields of different crops are highly dependent on climatic variables (temperatures and precipitation) and technical progress. With the climatic scenarios of the HadCM3 model, they project that the impact of climatic variables on cereals would be significant by 2030 and that this impact will be even more accentuated for bread wheat. Finally, the study has shown that the region will record in 2030 cereal yield losses of the order of 2.04%, 9.62%, and 6.78% respectively for durum wheat, bread wheat, and barley. In most of these studies, it appears that climatic factors (temperatures and precipitation) negatively influence not only production (or crop yields) but also agricultural income. This negative influence is perceived differently from one region to another.

3. THEORETICAL MODEL

Despite the willingness of the United Nations and governments to combat the negative effects of climate change through conferences and conventions, many authors have spoken out not only on the phenomenon of climate change but also on vulnerability and adaptation from agriculture to the increasing variation of the climate. There are two main approaches to assessing the impact of climate change on agriculture. They differ mainly by their methodology, which is oriented on one side towards agronomy and the other towards the economy. We find the production function approach and the Ricardian approach [29].

The Ricardian approach consists of expressing the net agricultural incomes according to climatic, edaphic variables, etc. This method is widely used in cross-sectional studies to examine the impact of climate variables [31,35]. The evaluation of the effects of climatic variables on agriculture by the Ricardian approach offers a wide possibility of analysis, from the economic and agronomic point of view. However, we cannot identify an adaptation strategy through this approach, but rather assess the relevance of the adaptation measures already undertaken. "Ricardian model" Induces the contribution of temperature and rainfall to agricultural productivity by examining the link between the price of agricultural land and the climate [36]. The Ricardian approach is based on land rent, which is considered to be the net agricultural income from the best use of the land. Land rent represents the net production of the land.

The agronomic approach, commonly called the production function approach, is based on the existence of a production function for any crop, which links the production (or yield) of the crop to its biophysical environment. This approach directly estimates yield change from crop response models. It measures the impact of climate change on yield, by varying the levels of climatic stimuli. It is also based on an experimental approach that attempts to measure the direct effects of climate change on different crops and their input needs [29].

Unlike the Ricardian approach, the production function approach makes it possible to appreciate the effects of the interaction of climatic variables on production. However, this approach tends to overestimate the damage linked to climatic variables because it does not take into account compensatory responses of long duration such as substitutions, adaptations, and new activities which can displace obsolete activities [37] cited by [16].

4. METHODS

Through the literature review, two approaches stand out in the context of this study, we opted for the production function approach because it will allow us to appreciate the impact of climatic variables on the productivity of cereal crops by considering the interaction effect. These results offer an idealistic presentation of the phases of cultural production, which tends to give results that are different from real-world conditions [34]. Also, it allows measuring not only the effect of first- and second-degree of climatic variables but also the effect of crossed climatic variables [16]. It is a model that is more representative and adaptable to our research question. The production function approach attempts to explain the variation in crop yields by the variation in climatic variables. It measures the effect of climate change on agricultural yield.

From the standard model, we have chosen the semi-logarithmic functional form in the context of this paper for the estimation of the variation of Sorghum yield as a function of climatic variables and the trend just as they did [38,34].

Thus, the functional form of our model for estimating the impact of climatic variables and technical progress on yield is as the following:

$$\log y_{it} = f(p_t, t_t, trend) \quad (1)$$

Where t is the average yield for year t,

p_t is the mean precipitation for year t,

t_t is the average temperature for year t,

$trend$ is the technical progress,

it are respectively the index of climate variables and the year.

In Mali, the rainy season generally starts from May to October, the date of sowing of sorghum crops is between June and July and the date of maturity and harvest is from August to September [39]. Throughout their development cycle, grains need water. The periods of June-July and August-September are however critical for the cultivation of sorghum in Mali. The data of the climatic variables collected are therefore the precipitation and temperatures of the months from June to September.

We have divided the season into two periods to analyze the temporal distribution of rainfall and temperatures observed during the crop years on the yield of sorghum. These are the sowing period (June-July) and the maturity and harvest period (August-September). The climatic variables (precipitation and temperature), considered in our empirical analysis, are those relating to the critical periods of the cultivation of sorghum in the Cercle of Koutiala. Thus, the functional model is as follows:

$$\log y_t = \beta_0 + \beta_1 Pjj_t + \beta_2 Pjj_t^2 + \beta_3 Tjj_t + \beta_4 Tjj_t^2 + \beta_5 Pas_t + \beta_6 Pas_t^2 + \beta_7 Tas_t + \beta_8 Tas_t^2 + \beta_9 (Pjj_t x Tjj_t) + \beta_{10} (Pas_t x Tas_t) + \beta_{11} trend + \varepsilon_t \quad (2)$$

y_t : the mean yield of sorghum year t

Pjj_t: the mean precipitation of June-July for year t

Pas_t: the mean precipitation of August-September for year t

Tjj_t: the average of June-July temperature for year t

Tas_t: the average of August-September temperature for year t

$trend$: the time trend, proxy variable to technical progress

t: year with (t_1, t_2, ……………., t_{30})

β_0 : constant

$\boldsymbol{\varepsilon_t}$ **:** error term

The parameters β are parameters to be estimated.

5. RESULTS AND DISCUSSION

5.1 Results

In the estimation procedure, the climatic variables and the trend have been integrated. The parameters of the model were estimated using the Ordinary Least Square Method (OLS). The overall regression evaluation was done with the Fisher-Snedecor test and the coefficient of determination (R^2) and the individual significance of parameters are evaluated by the Student test.

The stationary test was done to ensure that the variables used in the equation are stationary. Some variables are subject to high variability over time, so it is necessary to determine their integration order. Also, the determination of the integration order allows the choice of the best estimation method. Although, there are several tests. These include the Dickey-Fuller (DF) test, the Dickey-Fuller Augmented (ADF) test, and the Phillips-Perron (PP) test. [40] shows that the results of the ADF and PP tests are almost identical. Therefore, the ADF test will be used to determine the stationary nature of the variables used. The null hypothesis is that the variable contains a unit root, and the alternative is that the variable was generated by a stationary process. A nonstationary series is called an integrated “d” series if, after being differentiated “d” times, it becomes stationary. They say the series has a unit root.

The decision rule is as follows:

- if the value of the ADF statistic is greater than the critical value read on the table, the unit root hypothesis cannot be rejected; the series is not stationary,
- Otherwise, the assumption of a unit root was rejected; the series is therefore stationary.

These results in Table 1 show that all variables in this study are stationary at an integrated level of order 0.

The probability of skewness (Jarque–Bera test) is 0.3918 implying that skewness is asymptotically normally distributed (P-value of skewness > 0.05). Finally, chi (2) is 0.4210 which is greater than 0.05 implying its significance at the 5% level. Therefore, according to the Skewness test for normality, residuals show normal distribution.

Ramsey's test for model specification indicates that the estimated model is well specified because the calculated value 2.23 is less than the tabulated critical value 2.37 at ($F^{0.05}_{(11;18)}$).

The data have been divided into subgroups (1986-2000 and 2001-2015) for the Chow test, this test is used to determine whether the independent variables have different impacts on different subgroups. Chow stability test of the model using the two (2) subgroups shows that the estimated model is stable over the study period. Indeed, the calculated statistic (F*= 0.1104) for the model is less than the tabulated value of 4.00 at ($F^{0.05}_{(12;6)}$).

The coefficient of determination R^2 is 0.65, indicating that the model explains a large variation in yield. The adjusted R^2 coefficient is 0.4327. This explains that 43.27% of the yield variation is due to precipitation and temperature.

In Table 2 below, the coefficient for the mean precipitation variable for June-July (the beginning of cropping) is positive and statistically significant at the 5% level. The coefficient of the precipitation variable June-July square is negative and significant at the 5% level.

This implies that the increase in precipitation during June and July impacts positively the yield of sorghum meanwhile the square of the same variable up to certain threshold level impacts negatively the sorghum yield. Therefore, the plants at the beginning of the season need a certain amount of rain to develop and an excess of this rainfall is harmful to the sown crops [2]. Crops at this stage are very weak to withstand heavy rainfall which could flood them (loss of yield).

Like [11], we have captured here the risk of excess water to which crops are highly exposed. However, the coefficient of the mean precipitation variable during August and September (in the middle of the season) is positive and significant at the 5% level. This means that the precipitation of August-September positively affects the yield. Which responded to the expected result. According to [41], sorghum consumes water efficiently and is very resistant to intense and fortuitous hydride deficits. The result can also be explained by the fact that the water requirements of sorghum increase during the cycle to reach its maximum during the stage of flowering (around 6 to 7 mm/day) [42]. However, sorghum fears excess water; similarly, a very rainy period during the maturation period can reduce the quality of production [43]. His result is contrary to the result found by [32] in his study on the impact of climate change on agricultural income in Burkina Faso. He found that the relationship between agricultural income and the precipitation of the rainy season is U-shaped because the first order of this variable is negative and significant and the second order is positive and not significant. Furthermore, the average temperature of June and July has no significant effect on the variation in yield, the coefficients of this variable and its square are not statistically significant. On the other hand, the coefficient of the average temperature of August and September is negative and significant and its square is significant and positive. This means that the drop in yield is a function of the rise in temperature during the period August-September up to a certain threshold. Sorghum growth is reduced when the ambient temperature is below 20°C; the optimum temperature for vegetative growth is often around 30-34°C [43]. Indeed, sorghum is a dry crop and most crops stop growing when the temperature drops below a critical level.

Likewise, very high temperatures (above 30-35°C) harm growth [20]. This result is similar to those found by [36], in his study of the effects of drought in southwest Zimbabwe. He says that above certain temperature thresholds, agricultural yields can decrease because the acceleration of the growth process is accompanied by less grain production. The increase in temperature changes the ability of plants to retain and use moisture. Up to a certain threshold, productivity improves when the temperature goes from cold to warm, then deteriorates when it goes from warm to hot [44].

Besides, the interaction variables between precipitation and temperature for both periods (June-July and August-September) negatively affect the yield of sorghum. They are respectively negative and significant at 10% and 5%. This shows that the increase in temperature and precipitation combined during the same period leads to a decrease in the yield of sorghum for both periods. However, an increase in precipitation leads to a drop in temperature. This result corroborates that found by [34] in their studies on the impact of climate change on the productivity of cereal crops in the Béja region of Tunisia. An increase in temperature and precipitation during the same period favors the appearance of plant diseases, and consequently, would cause a reduction in the yield of cereals.

Besides, it should be noted that the signs of the squared variable and the variable are opposite; which confirms the non-linear relationship between yield and climatic variables (temperature and precipitation). The study can, therefore, conclude that the relationship between yield and climatic variables is quadratic. This is similar to the results found by [34], in their studies on the impact of climate change on agriculture in Tunisia and Burkina Faso. This explains why agriculture depends on climate. As for the Trend variable, used here as a proxy for technical progress [45], it has no impact on the yield of sorghum in the Cercle of Koutiala. It is not significant.

Table 1. Stationary Test of ADF

Variables	ADF Stat	Stat table	Decisions	Integration order
Log Yield (logy)	-6.56	-3.50	Stationary	I (0)
Precipitation June-July (Pjj)	-8.26	-3.50	Stationary	I (0)
Precipitation August-Sept (Pas)	-7.41	-3.50	Stationary	I (0)
Temperature June-July (Tjj)	-5.14	-3.50	Stationary	I (0)
Temperature August-Sept (Tas)	-7.30	-3.50	Stationary	I (0)

Source: author, Dickey-Fuller stationary test (ADF)

Table 2. Estimation by the approach of the production function

Variables	Coefficient	T-statistic
Mean precipitation of June-July (Pjj)	0.0871**	2.30
Mean precipitation of June-July Square (Pjj)sq	-0.0001**	-2.67
Average of June-July temperature (Tjj)	-0.4501	-0.23
Average of June-July temperature Square (Tjj)sq	0.0114	0.35
Mean precipitation of August-Sept (Pas)	0.0787**	2.39
Mean precipitation of August-Sept Square (Pas)sq	-7.67E-06	-1.34
Average of August-Sept temperature (Tas)	-5.7525**	-2.27
Average of August-Sept temperature Square (Tas)sq	0.1080**	2.37
Interaction precip. and temp. average June-July (PTjj)	-0.0020*	-2.02
Interaction precip. and temp. average Aug-Sept (PTas)	-0.0027**	-2.39
Trend	0.0016	0.91
Constant	80.5354	1.57
R^2	0.65	
Adjusted R^2	0.43	
F (11, 18)	3.01	
DW	2.02	

Source: author, estimation of the model
*Level of significance: *=10%; **=5%; ***=1%*

Table 3. Marginal effects

Variables	ey/dx	T statistic
Mean precipitation of June-July (Pjj)	0.0290**	2.30
Average of June-July temperature (Tjj)	-0.1498	-0.23
Mean precipitation of August-Sept (Pas)	0.0262**	2.39
Average of August-Sept temperature (Tas)	1.9146**	-2.27
Interaction precip. and temp. average June-July (PTjj)	-0.0007*	-2.02
Interaction precip. and temp. average Aug-Sept (PTas)	-0.0009**	-2.39

Source: author, results from the data
*Level of significance: *=10%; **=5%; ***=1%*

5.2 Discussion

To assess the impact of climatic variables on the yield of sorghum in the Cercle of Koutiala in southern Mali, the semi elasticity of the yield concerning temperature and precipitation has been used. The climatic variables are calculated based on the average temperatures and precipitation for June to September (agricultural season in Mali). The same procedure was applied by [32,29] to analyze the impact of climate change on agriculture in Burkina Faso and Tunisia. As shown in Table 3, the effects of climatic variables are positive and significant at the 5% threshold for rainfall from June to September. Thus, if the average rainfall for the period from June to July and from August to September increase by 1 mm each, the yield of sorghum will increase respectively by 0.029% and 0.026% on average. This explains that the rainfall during the agricultural seasons in Mali is very important for the productivity of sorghum. This result shows that the cultivation of sorghum in the Koutiala area in Mali depends on rainfall and confirms the hypothesis of [46], stating that cereal cultivation is almost exclusively extensive and depends on the rains in the Sahel country.

Furthermore, the average temperature coefficient for the months of June-July is negative and not significant. However, for the period August-September is negative and significant. This explains that the rise in average temperatures of 1°C during the months of August-September, leads to a decrease in the yield of sorghum around 1.91% on average. Necessarily high temperature during the maturity period is unfavorable to sorghum productivity because it promotes the main diseases of the ears and panicles.

A parasitic plant (Striga) constitutes a significant danger for millet and sorghum and infection with Striga is favored by drought [47]. In general, the temperature rise has a negative impact on cereal crops in the Sahel countries. Authors such as [32,2] have demonstrated that in their studies on the impact of climate change on agriculture and food security in Burkina Faso and Senegal.

Coefficients of interaction are negative and significant respectively at 10% and 5%. This implies that the increase in average precipitation of 1 mm combined with an increase in average temperatures by 1°C during the two periods (June-July and August-September) lead to a decrease in the yield of about respectively 0.0007% and 0009%. An increase in precipitation combined with an increase in temperatures is detrimental to agricultural yield. This shows that rainfed agriculture in the Koutiala area is mainly related to climatic conditions especially in case of increased temperatures.

6. CONCLUSION

The Malian economy is characterized by a strong predominance of the agricultural sector which employs around 75% of the active population and it contributes to the GDP about 40% according to the Ministry of Agriculture in 2010. The Cercle of Koutiala in the region of Sikasso has an important place in Mali sorghum production by producing 12% of national production in 2011. From the obtained results, the Koutiala area is experiencing the adverse effects of climate change on sorghum yield, especially the effects of precipitation and temperature.

Thus, it is urgent to find adequate solutions in the context of current climate change to ensure the improvement of cereal production and food security in Mali. This study was looking for the following results: (a) the increase in precipitation during the period June-July is beneficial for the yield of sorghum up to a threshold. (b) An increase in the precipitation during the August-September period is also beneficial for the yield. (c) An increase in temperature during the

August-September period is a threat to the yield of the sorghum, as well as the interaction of the two climatic variables (temperature and precipitation) during the two periods (June-July and August-September).

These different results highlight the problem of water management. The results of our study show that the control of climatic factors makes it possible to apprehend 43.27% (value of Adjusted R^2) of the variability of the yield.

It is important and necessary to take adequate measures to mitigate the negative impacts of climate on the productivity of sorghum in the Cercle of Koutiala. Climate change has become a major factor impacting agriculture in the Cercle of Koutiala. A fact that requires the involvement of all levels of society. The main objective of this work was to analyze the impact of climatic variables (temperature and precipitation) on sorghum productivity in the Cercle of Koutiala in Mali. It was conducted using panel data from the Regional Directorate of Agriculture of sorghum production of the study area and climatic data from the Regional Meteorology Station from 1986 to 2015. The production function approach was used to estimate the climatic variables (temperatures and precipitation). Using the semi-logarithmic form, the study found that climatic variables both affected the yield of sorghum up to a certain threshold before becoming beneficial or detrimental to sorghum.

To tackle the uncertainty on yield and the effects of climatic variables on sorghum productivity, it is urgent to develop new techniques of adaptations by providing farmers with improving and drought-resistant seeds of sorghum. Equip farmers to cope with climate change by training them to news climate-smart agriculture techniques and this through agricultural extensions services improvement. Implementing effective

For that, adaptation strategies, such as access to improved seed, introduce smart agriculture such as technology of micro-dose in the system of cereal in Mali and increasing irrigation infrastructure could reduce the cereal production's vulnerability to climate shockwaves.

COMPETING INTERESTS

Author has declared that no competing interests exist.

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